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R-process pattern in the Very-Metal-Poor Halo Star CS 31082-001

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Abstract. The very-metal-poor halo star CS 31082-001 was discovered to be very strongly r-process-enhanced during the course of a VLT+UVES high-resolution follow-up of metal-poor stars identified in the HK survey of Beers & colleagues. Both the strong n-capture element enhancement and the low carbon and nitrogen content of the star (reducing the CN molecular band contamination) led to the first ^{238}U abundance measurement in a stellar spectrum (Cayrel et al. 2001), and the opportunity to use both radioactive species ^{238}U and ^{232}Th for dating the progenitor to this star. However, age computations all rely on the hypothesis that the r-process pattern is solar, as this was indeed observed in the other famous r-process-enhanced very metal poor stars CS 22892-052 (Sneden et al. 1996, 2000) and in HD 115444 (Westin et al. 2000). Here, we investigate whether this hypothesis is verified also for CS 31082-001, using a preliminary analysis of over 20 abundances of n-capture elements in the range Z=38 to Z=92.

Cayrel et al. (2001; this volume) discuss the discovery and importance of CS 31082-001, and here we report a summary of a preliminary abundance analysis for this star (Table 1).

The n-capture element abundances (relative to iron, [X/Fe]) of CS 31082-001 are compared in Fig. 1-a to those of CS 22892-052 and HD 115444, showing that the overabundance of the Z>56 n-capture elements in CS 31082-001 is almost identical to that of CS 22892-052, with a mean overabundance of [X/Fe]$\sim$+1.7dex. These two stars are therefore the most extreme cases of n-capture element enhancement in halo stars, far more extreme than HD 115444. Furthermore, the abundance pattern of the 56<Z<70 elements in CS 31082-001 are indistinguishable from that of CS 22892-052 or HD 115444. In contrast, the abundance pattern of Z>70 seems to be more abundant in CS 31082-001 than

in CS 22892-052 or HD 115444, including thorium, which is a factor four more abundant in CS 31082-001 than in CS 22892-052. Therefore the $\log\epsilon$(Th/Eu) ratio, often used as an age indicator, is a factor 3 larger in CS 31082-001 than in CS 22892-052.

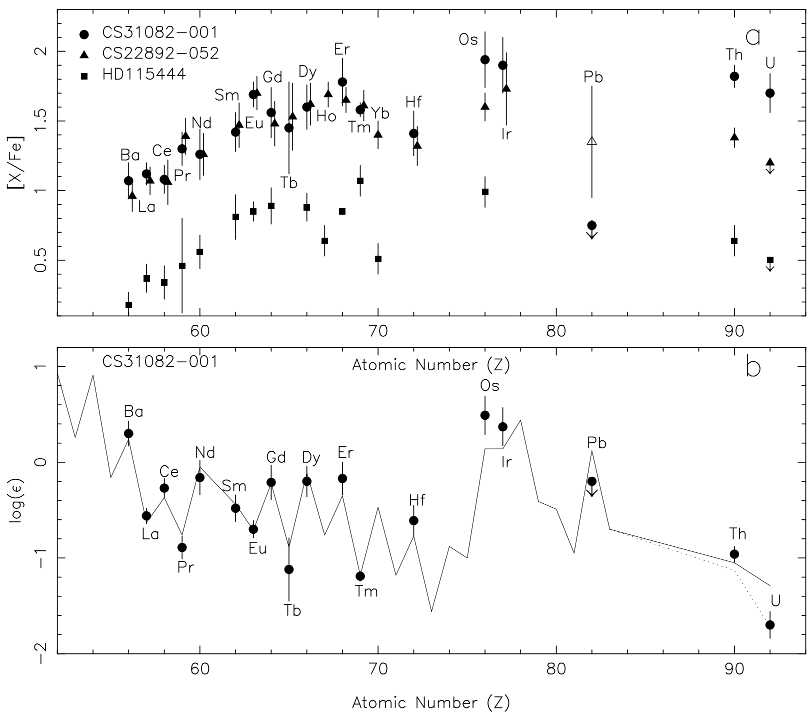

Figure 1. N-capture abundances pattern in CS 31082-001 compared to: *a*- CS 22892-052 and HD 115444. (The abscissa for CS 22892-052 has been artificially shifted by +0.3 for readability). *b*- to the solar system r-process (Burris et al. 2000), scaled to match the $56 \geq Z \leq 72$ abundances of CS 31082-001. The radioactive species (Th and U) solar system abundances are the values at the time of formation of the solar system. The dotted line show the abundances observed *today* for these two species.

In Fig. 1-b, the abundance pattern of the n-capture elements of CS 31082-001 are compared to solar system r-process pattern (as of Burris et al. 2000) scaled to match the mean $56 \geq Z \leq 72$ n-capture elements abundance of CS 31082-001 $\log\epsilon_{CS\,31082-001} - \log\epsilon_{SS}$=-1.22±0.03 ($\sigma$=0.10 over 13 elements). Here again, whereas the $56<Z<70$ elements in CS 31082-001 are very well reproduced by a solar r-process, the $Z>70$ elements are behaving in a somewhat more erratic way. While Os and Ir seem to be more abundant than the scaled solar r-process, Pb is notably underabundant (even the strongest line at 4057Å was not detected).

This has the very interesting consequence that the [Th/Eu] ratio (Eu or any other $56 \leq Z \leq 70$ element) would predict an epoch of formation of the n-capture elements present in CS 31082-001 *later* than the epoch of formation of the n-capture elements which enriched the solar system ! This conflicts with

Table 1. Neutron-capture elements abundances in CS 31082-001.

El.	Z	$log\epsilon$	σ	N_{lines}	El.	Z	$log\epsilon$	σ	N_{lines}
Sr	38	0.68	0.09	4	Tb	65	-1.12	0.33	7
Y	39	-0.16	0.11	9	Dy	66	-0.20	0.16	7
Zr	40	0.47	0.13	5	Er	68	-0.17	0.17	5
Ba	56	0.30	0.13	7	Tm	69	-1.19	0.05	3
La	57	-0.56	0.08	4	Hf	72	-0.61	0.16	2
Ce	58	-0.27	0.10	9	Os	76	0.49	0.20	3
Pr	59	-0.89	0.12	4	Ir	77	0.37	0.2	1
Nd	60	-0.16	0.18	17	Pb	82	<-0.2:		1
Sm	62	-0.48	0.14	9	Th	90	-0.96	0.08	11
Eu	63	-0.70	0.09	9	U	92	-1.70	0.14	1
Gd	64	-0.21	0.18	7					

T_{eff} = 4825K $\log g = 1.5$ $\xi_{micro} = 1.8\mathrm{kms}^{-1}$ [Fe/H]=-2.9

the observed U/Th ratios observed in CS 31082-001 and the solar system: ^{238}U has a half-life a factor 3 shorter than ^{232}Th, so if the r-process elements of CS 31082-001 were produced after those of the solar system, the U/Th would be significantly smaller in CS 31082-001 than in the solar-system (dotted line), which is not observed. In fact, the age of CS 31082-001 predicted from the [Th/Eu] ratio conflicts with those from the [U/Th] [U/Os] or [U/Ir] ratios.

Beyond the issue of the age of this particular star, the fact that the Z>70 elements pattern does not seem to be well-matched by those of other similar stars (CS 22892-052, HD 115444) nor the solar-system r-process elements is worrisome concerning the used of Th/Eu (or U/Eu) ratios as age-tracers. The normalization of radioactive elements abundances to elements *in the same mass-range* becomes indispensable.

The reason for the discrepancy of the Z>70 elements could be a direct consequence of chemical inhomogeneities in the early Galaxy: the ISM giving birth to very metal poor stars has probably only been polluted by a very limited number of supernovae, and hence it is possible that we now see the various outcomes of single events. Only *significant samples* of such n-capture enhanced elements will give clues to this issue. Christlieb et al. (this volume) suggest one method for quickly achieving this goal.

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